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Energy saving, implementation of solar energy and other renewable energy sources for energy supply in rural areas of Russia

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Abstract

The project of large-scale stage-by-stage implementation of energy systems based on solar energy and other renewable energy sources (RES) in rural settlements of Russia has been worked out. Research was made based on the analysis of regional, climatic, social, economical and technical factors, proposed complex approach to energy supply of rural buildings and predictive estimates. Priorities, sequence of actions and the values of interstage and final indicators have been defined. The issues of RES implementations and measures on energy saving over vast, mainly poorly populated, rural territories have been considered.

Peer-review under responsibility of the Euro-Mediterranean Institute for Sustainable Development (EUMISD)

Keywords: Solar Energy; Rnewable Energy Sources; Rural Areas; Rural Settlements; Project of Large-Scale Stage-by-Stage Implementation of Systems Based on RES; Energy Saving; Complex Energy Supply Systems.

1. Conditions for large-scale implementation of complex energy systems based on RES

1.1. Condition of energy supply in Russia rural settlements

The energetics of agriculture have some specific features: dispersed of rural consumers, small unit capacity, great length of electrical, thermal, and gas networks, large sparsely populated territories where the agricultural production is carried out but which have no centralized energy supply. These features impose additional requirements for energy supply systems; substantial transition line wear off and low quality of supply, failures and power losses in lines. The agriculture possesses the greatest potential for disclosing RES advantages with the simultaneous decision of the most acute problems of rural energy supply.

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The major part of rural settlements in our country is located in thinly populated and remote areas and the problem of their low power provision level is vitally important. This problem affects substantially the living conditions of rural population, demographic situation, as well as the maintaining and development of agricultural production on these territories.

A substantial part of localities in Russia has no access to power supply grids and are powered from petrol- or diesel-generators. Every year, 6 to 8 m t. fuels and lubricants (diesel fuel, gasoline, fuel oil, lubricant oil) and 25 to 30 m t. coal are imported to the regions of Far North, Far East and Siberia where power supply is stand-alone based. Due to transportation cost rise the price of fuels in the regions mentioned above is two or even three times higher compared with that of producer. More than half of territories' budgets has to be spent on fuels and their transportation. In some cases lack of fuel endangers human lives, and the governmental bodies have to solve the problem with the help of EMERCOM of Russia.

According to the agricultural census data, less than 35% of large and medium agricultural enterprises have an access to the centralized gas supply system and only 20% of them are connected to centralized heating systems. If even the gasification program is going to be completely implemented, the former indicator will grow not more than by 10%**.**

Accelerating power rates, transmission lines wear out and high prices for capacity connections make the power supply problem urgent also for rural settlements located in densely populated areas with centralized power.

In areas with centralized power supply under-power may occur, for example, due to a certain limit established in the course of installation of transformer substation having a specific rating and subsequent power uniform distribution in accordance with the number of sectors or due to a flexible power tariff (when the price per power unit is several times higher for capacities exceeding a certain established threshold level). It is vitally important to install power generation capacities at the "end points" of extended local power distribution lines of 6kV to 10kV. Power interruptions for consumers connected to such power lines may take many hours which aggravate the damage to customers not compensated by utilities [1].

1.2. Condition of RES use in Russia rural settlements

The condition of RES use in Russia is as follows: single, individual installations, the lack of standard installations and systems.

Issues of state support belong to the most important and undeveloped as far as the implementation of renewable energy sources on rural territories of Russia is concerned. The existing general concepts do not take into account, to a sufficient extent, all components of economic efficiency, neither the advantages of renewable energy sources nor the drawbacks of competing power technologies, as well as all possibilities of RES efficiency improvement. A wide range of development specific features of bouth rural settlements and renewable energy technologies makes it impossible application to apply economical solutions of other countries as they are.

Rural settlements present the best starting platform to launch a large-scale implementation of RES in Russia and may serve the driver that will bring this branch of power industry on the level of EU countries and USA. Rural areas provide the maximum possible variety of local conditions and the highest possible effectiveness of solar energy and other RES practical application. The major problems of rural territories in terms of the large power networks development run into advantages as far as the implementation of RES-based integrated energy systems is concerned. Low per-unit capacity of power installations and their scattering over large remote areas provide the maximum implementation efficiency of these systems reducing the payback period and proving the expediency of their use. Moreover, these systems provide the opportunity to maintain the up-to-date level of power availability in rural settlements, and their implementation is, under most circumstances, the only option to achieve this goal. At the same time these are exactly rural areas that are most sensitive in terms of environmental requirements that have to be met while implementing power equipment.

For rural settlements, buildings and territories of environmentally dedicated villages, where the natural environmental conditions are stable and on a satisfactory level, the trend of substantial increase of power generation from systems based on RES is clear.

For the most regions of Russia the introduction of stand-alone and complex energy supply systems using renewable energy is the most expedient. Generally, integrated systems based on different kinds of RES shall be able to employ all of the effective period of their operation. Such systems have to be designed so that the renewable energy part of the system performs function of the primary source of power while the other energy sources take the load only in the case that the primary source fails (or its capacity is currently insufficient).

In comparison with the traditional ways of energy supply, when using RES we eliminate the following:

- electric networks laying costs of RUB 500 thousand/km, gas networks laying costs of RUB 210 thousand/km;
- networks losses: 20% to 30% in electrical networks, up to 60% in heating networks;
- wear and tear and required reconstruction of networks equipment of up to 80%;
- increase in the connection charge (over RUB 50 thousand/kW);
- energy supply failures, poor quality of energy supply leading to losses and irreparable damages;
- fuel and lubricant delivery costs; difficulties in (or impossibility of) laying networks and delivering fuel and lubricants;
- increase in the energy supply cost because of traditional resources (on average 15% per year) and their exhaustibility;
- ecology problems: environmental pollution, CO_2 emissions, etc. and, hence, deterioration of living conditions of rural population, reduction in productivity and quality of agricultural products, growth of sickness rate, etc.

1.3. Resources and cost. Basic variant of systems

For work we used the RES data presented in [2 - 7] and publications [1, 8-11] first of all.

Table 1 presents an overall evaluation of solar energy industry in Russia and that of other RES.

Table 1. Evaluation renewable energy sources potential in Russia.

Resource	Aggregate potential (million TOSF/year)	Technical potential (million TOSF/year)		Economic potential (million TOSF*/year)	
		2010	2020	2010	2020
Solar energy	**2 205400**	**9695**	**29900**	**62,5**	**180**
Wind energy	44326	2216	3324	11	18
Small hydro	402	126	160	70	91
Biomass	467	129	170	69	88
Geothermal energy	29200	11869	1300	114	125
Low potential heat	563	194	220	53	70

* Ton of standard fuel

Table 2 presents the range of values of specific cost (per capacity unit) for RES-based power supply systems in 2011 and 2020 where estimations for 2020 were made in assumption that a mass-scale implementation of such systems would start in accordance with the relevant development programs.

Table 2. Cost of 1kW of installed capacity for RES-based power supply systems.

RES	*2011*	*2020*
Solar PV	5000-9000	2500-3500
Solar heating	2000-3140	1700-2000
Biomass	1000-2500	950-2100
Micro GES	400-1450	300-1140
Wind power	1350-3900	1200-3200
Geothermal	1700-5700	1500-5000
Low potential heat	4500-6680	3800-4800

Among all kinds of RES, photoelectric power have experienced the most intensive growth (to 50% annually) in spite that the cost of solar PV systems is rather high. Hopefully, their price tends to a 2 to 3 times reduction by 2020 with regard to the current rate of development and implementation of new technologies in this field. The major advantage of solar power is that solar energy is available allover the globe. Solar batteries have the greatest potential of their economical and technical parameters improvement and intensive growth of production rate. Their installed capacity ranges within particularly wide limits and they present the most stringent option in terms of investments while estimating the indicators of RES implementation. Therefore, in general calculations, it is advisable to consider systems with solar power supply as the basic variant of systems (BVS). The size of such systems for rural applications ranges from 2kW to 10kW of installed capacity. They are capable to supply power to 1 to 30 homes depending on regional conditions and power requirements.

2. Priorities, sequence of actions and indicators

2.1. General considerations

The proposed project of large-scale stage-by-stage implementation of energy systems based on solar energy and other RES in rural settlements of Russia is designed for 7 years. The main target indicator is the commissioning of at least 190 thousand energy-efficient stand-alone and complex energy systems using renewable energy sources [12].

The target object of energy supply is a building, a structure or a private building. The installed capacity requirement is 0.2 to 10 kW. The power consumption of one object (group of houses) is to 20 kWh per day and that of a rural settlement is up to 1.5MWh a day. The initial total demand in systems is based on the data on the number of people who are the potential consumers and the power consumption rate for the target areas (Goskomstat and GNU VNIIESH) [13-15].

The systems are mainly designed for the areas with remote and distributed consumers who do not have the access to centralized networks. Therefore up to 100000 of power systems will be of stand-alone type.

Research was performed on the basis of the current values of indicators, as well as those of prospective estimations. The project is designed for implementation within the next 3 years. Corresponding modifications and amendments have to be considered in the case that the implementation period is shifted (substantially) in time or the project will be applied to another territory. The project is presented in its generalized form.

Taking the current situation in Russia into account, estimations were made in accordance with the most unfavorable variant to insure attaining the most probable results of implementation.

The variant under consideration is also optimized over the local indicators of building conditions, available power and social standard of living in rural settlements [13-20].

2.2. Procedure for determining the values of the target indicators and correlations between them

I. Defining the total number of systems $N = 190000$ pc.

At the same time the average price as the cost of BVS (PV system) can be defined. The possible aggregate capital investments and year by year investments can be determined. In determining the total number of systems, we proceed from the following:

- existing requirements;
- number contemplated by the legislative acts of the Russian Federation;
- really possible maximum financing of the Program;
- experience of the renewable energy development abroad;
- forecasts of growth of each type of RES and their ratio;
- production status of each type of renewable energy sources and prospects of its growth;
- existing problems and difficulties of RES introduction.

Table 3 shows the number of implemented complex systems of energy supply of rural buildings equipped with RES by years and justification of increase in the number of systems to be implemented.

Table 3. Growth of the number of systems using RES for rural buildings.

Stage	Year	Number (thousand pc.)	Cost, based BVS (% total cost)
Step by step putting into operation, commissioning of potential capacities; development completion; pilot projects	1	3	1,6
	2	8	4,2
	3	16	8,4
Development implementation. Completion of the analysis, data collection on implementation conditions and creations of standard systems	4	28	14,7
	5	40	21,1
The development potential that was available by the launch of the Program has been implemented. The basic level of production has been reached.			
Substantial reduction of system cost	6	40	21,1
Introduction of new achievements. Beginning of mass introduction of a know-how and standard systems	7	55	28,9
	Total	190	100 (01.01.2015 -61512 million RUB)

II. Defining the share of each RES type.

In determining the number of systems by types and years, we also proceed from the following:

- gradual increase of production capacity and accumulation of experience in commissioning with the state support;
- ratio of RES requirement, prospects of other power supply and production possibilities;
- currently available potential of possibilities of system component production and imported equipment use possibilities;
- need of standard projects creation;
- conservative approach to the questions of RES use;
- condition of the legal and normative base, normative and technical base and necessity of its tuning-up;
- necessity of tuning up effective incentives for the introduction of RES systems;
- principles of determining expediency of RES application;
- availability of and outlooks for the introduction of developments and know-how;
- state of RES implementation.
- cost characteristics in combination with the possibility of systems creation for as many consumers as possible.

The expediency of use of any type of RES is determined by:

- the presence of this type of resource, its potential;
- the proximity of network sources and expediency of their use of or connection to them, including the factors of reliability, losses, wear and tear, etc.;
- the facility condition and stage at which the energy supply system is included in it (project or finished construction not allowing any significant changes); whether the system is made together with the facility or individually after its creation; whether ready, standard solutions are taken;
- the assumed needs of energy and load charts.

To define the year by year indicators of systems depending on their types we will start with those having the least fractional capacity:

1) The minimum capacity of systems on the basis of micro hydroelectric station is approximately equal to the maximum planned system capacity. Therefore we shall first define the for years distribution of number of systems using water resources, taking into account the amount of resource and production opportunities. Then we shall calculate their percentage in the total number.

2) To improve the power supply in areas having geothermal sources we shall choose the particular industrial installation with the minimum installation capacity of 500kW that costs RUB 34,500 thousand. These are 123 systems of medium price taking into account the largest coefficient of use (up to 70%). We accept this value for the calculation as a conditional number. We have to make the correction for the number of integral standard capacities (hydro-and geothermal resources).

III. We can estimate the number of systems using each resource type to be put in operation in the *i*-th year:

$$N^i_{RES} = a \cdot N^i$$

where N^i is the total number of systems put in operation in the *i*-th year, and a is the share of this resource in the total number of systems.

Let us define the cost and capacity of systems of particular resource to be put in operation within particular year C^i_{RES} and P^i_{RES} :

$$P^i_{RES} = C^i_{RES} \cdot c^i_{sp.RES} ,$$

where $c^i_{sp.RES}$ is the specific cost of capacity unit for system of this particular type in the *i*-th year determined from diagrams. Thus verifying equality shall be valid: $\sum C^i_{RES} = C^i$, where C^i is the capacity of systems to be put in operation within particular year.

The obtained results of calculations for each type of RES shall be entered into a final table.

In the diagrams, Fig. 1, 2, the year by year distribution of the main indicators of the implementation process is presented.

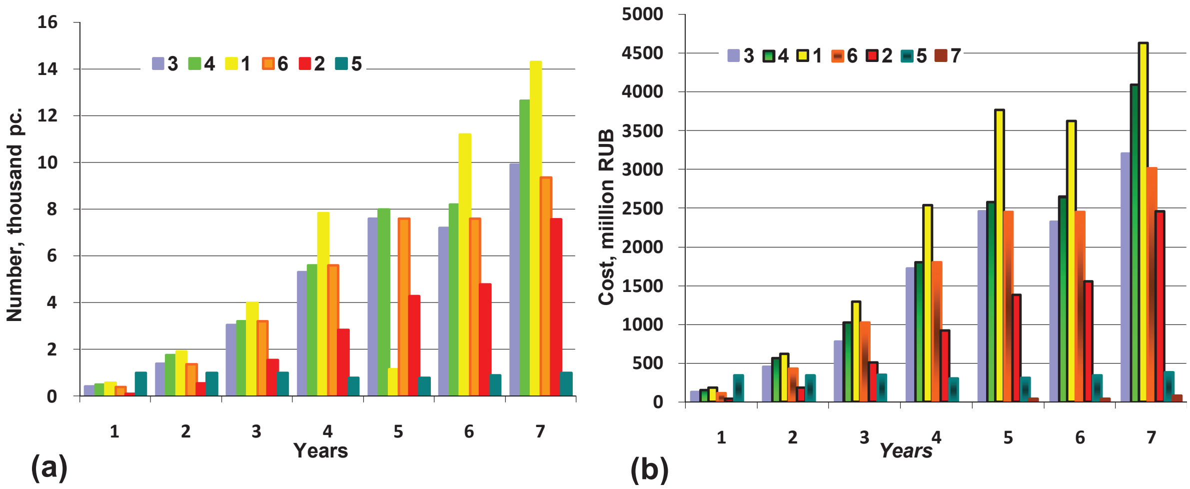


Fig. 1. (a) growth of the number of power systems using different types of RES to be put in operation; (b) cost of power systems using different types of RES (01.01.2015).
1- solar PV; 2 - low potential heat; 3 - wind power; 4 - biomass; 5 - micro GES; 6 – solar heating; 7 – geothermal.

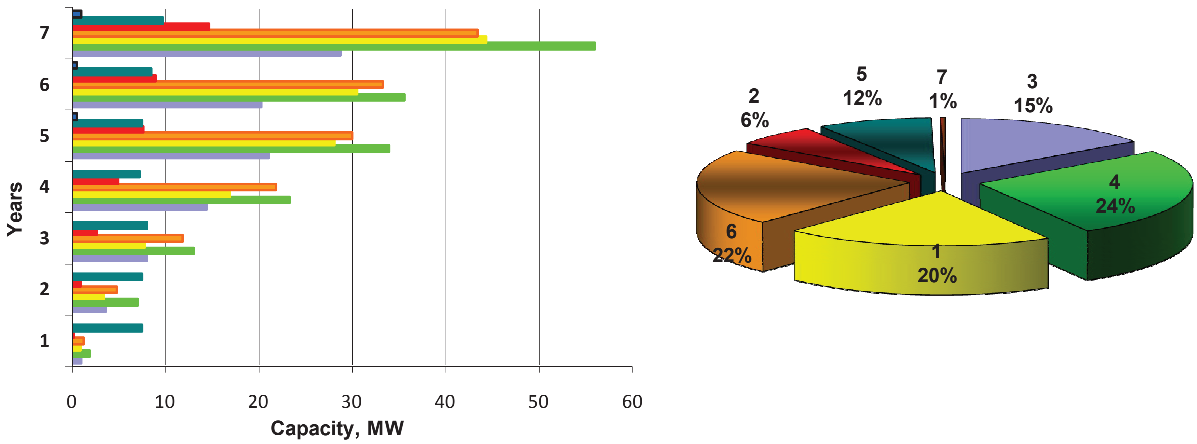


Fig. 2. Capacity of power supply systems using RES to be put in operation.
1- solar PV; 2 - low potential heat; 3 - wind power; 4 - biomass; 5 - micro GES; 6 – solar heating; 7 – geothermal.

3. Energy saving

In Russia, operation of individual solar systems is essentially greater affected by transmission and consuming equipment while the subject of energy supply is the building itself. The reason is that in Russia, unlike foreign countries, restrictive norms and standards in the sphere of energy saving are ineffective in practice, and the traditional “energy-is-no-object” approach. Energy resources consumption could be reduced by down to 70% as a result of measures taken in order to minimize energy consumption, and in this way, either to decries the demand in solar system installed power (and its cost, accordingly) or, on the base of the same investments ratio and installed power, to enhance the energy reliability and accessibility of a site and to extend the area of efficient system application providing the uniformity of technical level. For thermal systems the main problem are the heat losses in buildings. The major part of buildings were constructed in accordance with out of date norms and standards, and heat losses in them amount up to 60% to 80% of the aggregate consumption in the heating system.

As a result of actions on energy saving it is possible to reduce the system cost for one object owing to the reduction of capacity demanded (to redistribute assets, to increase the number of systems) without additional investments or, at the same cost, to provide a higher level of requirements and a higher comfort level for consumers of the system, i. e. to increase the level of actual power supply rate.

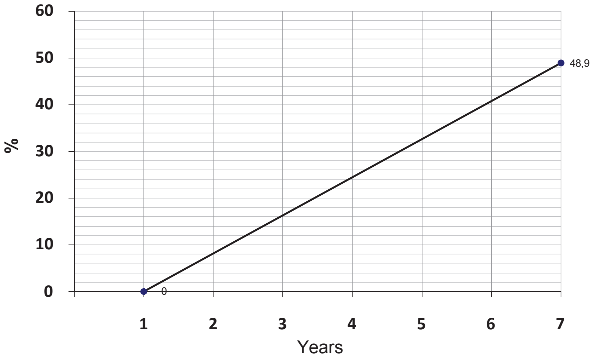
The effect of energy consumption reduction of buildings has been taken into account in the potential of systems’ capacity reduction in the *i*-th year for the implementation of energy saving measures ΔP^{i}_{ES} :

$$\Delta P^{i}_{ES} = \zeta \frac{K^{i}_{ES}}{100} P^{i}_{RES} = \mathrm{A}P^{i}_{RES}$$

where P^{i}_{RES} is the total installed capacity of the systems using a particular resource in the *i*-th year and K^{i}_{ES} is the value of power consumption reduction of buildings in the *i*-th year. We assume that the power consumption is uniform during the whole term of the project; ξ is the correction factor equal to 0.7 or 0.8 for power and heat supply, respectively.

The reduction of energy consumption by 48.9% in buildings was set as the target indicator in calculations. This indicator is chosen to meet the requirement of energy saving potential in Russia (45%). It is nearly the lower limit for rural buildings in residential sector. The stipulated energy saving potential for rural buildings in residential sector ranges from 45% to 75% depending on the building category.

The values of the calculated coefficients used for the evaluation of energy consumption reduction of buildings are shown in table 4. K^{i}_{ES} can be determined from the diagram, Fig. 3. Where there is an option of system using one and the same resource for both heat and power we have to choose the toughest alternative.



Year	K^{i}_{ES}	A, ξ=0,7	A, ξ=0,8
1	8	0,056	0,064
2	16,5	0,116	0,192
3	24,2	0,169	0,194
4	32,3	0,226	0,258
5	40,8	0,286	0,326
6	48,9	0,342	0,391

Fig. 3. Year by year power consumption of building.

Table 4 The coefficients for calculation of energy consumption reduction of buildings

Figure 4 presents diagrams that generalize the effect of energy saving measures on the implementation of RES-based power supply systems.

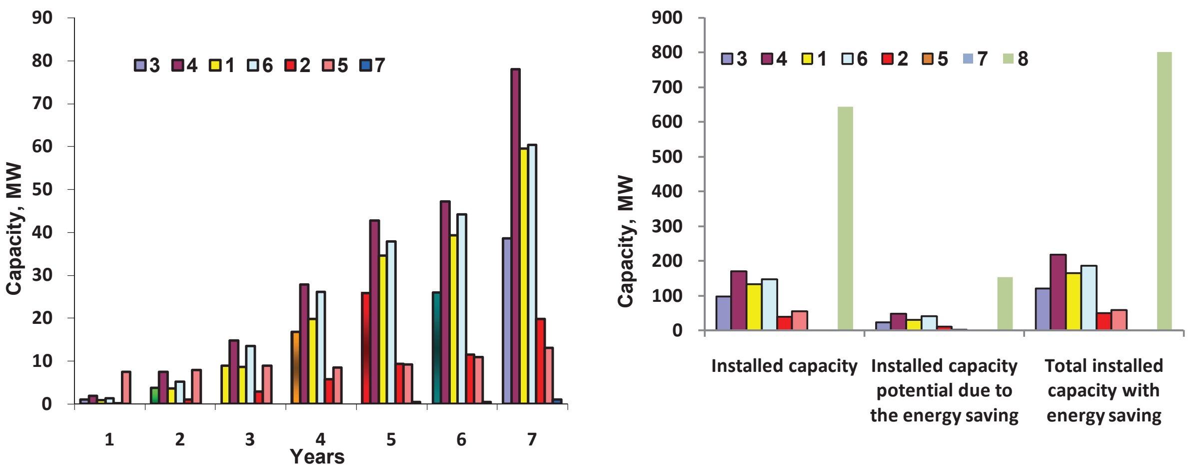


Fig. 4. Capacity of power supply systems using RES with energy saving.
1- solar PV; 2 - low potential heat; 3 - wind power; 4 - biomass; 5 - micro GES; 6 – solar heating; 7 – geothermal.; 8 - total installed capacity with energy saving

4. Conclusions

As a result of the project implementation the total installed capacity of systems will amount to 644,1MW. The potential of installed capacity demand of buildings will be 177,1MW owing to the reduction of energy consumption.

Putting into operation of 190 000 complex energy-efficient systems using renewable energy sources in accordance with the project will provide:

- to provide power for remote consumers and those not having access to centralized networks;
- to create the basis for wide implementation of energy supply systems using RES designed for rural consumers, and for the transition to the RES in all possible cases in the future;
- to evaluate the demand in RES and their advantages for rural areas;
- to identify emerging challenges applied to the conditions of specific sites and areas;
- to develop the optimal combinations for different areas and various kinds of resources;
- to develop the power supply systems using RES taking into account the specific requirements of rural infrastructure and acquired experience;
- to create a normative and guidance base, to develop recommendations for the equipment designing, implementation and sizing;
- to give a start to an industrial production of installations and systems, beginning with the introduction of individual samples, making the advantage of international experience;
- to launch a large-scale production of standard systems.

The resulting diagrams are shown in Fig. 4.

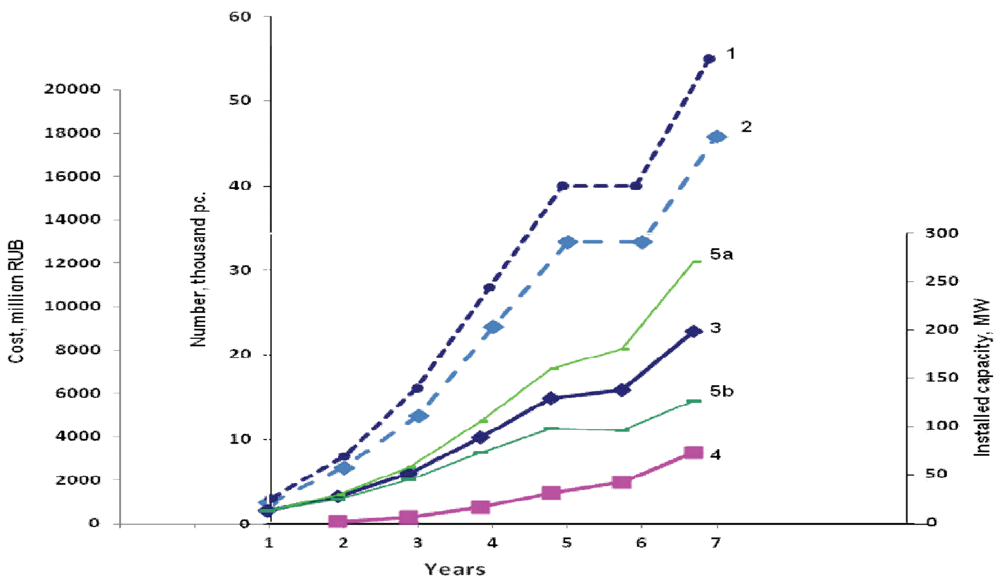


Fig. 4. Change of power supply systems' indicators in the course of implementation of the project.
1 - number of systems; 2- system cost; 3 - installed capacity; 4 - installed capacity potential due to the energy saving; 5a - growth potential of systems' installed capacity without an increase in the source equipment number; 5b - reduction of system capacity required owing to the energy saving.

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